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Research Paper

Investigations of adverse wind loads on a large cooling tower for the six-tower combination

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HIGHLIGHTS

- The wind tunnel tests on a group of six cooling towers are carried out.
- Twenty-seven types of pressure distribution curves are proposed.
- A fifteen-term trigonometric function is utilized to fit two wind load patterns.
- The local buckling factor and construction cost are adopted to evaluate wind effects.
- The most adverse wind load pattern of all is the symmetrical distribution.

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ABSTRACT

Wind-induced pressures are measured on a group of six cooling towers during a series of boundary layer wind tunnel tests, which varied among two tower arrangements, three tower spacings and sixteen wind directions. Based on the statistical results of wind pressures on the throat level, twenty-seven types of pressure distribution curves including nine symmetrical distributions and eighteen asymmetrical distributions are proposed and fitted by the fifteen-term trigonometric function with seven sine terms, seven cosine terms and one constant term. The local buckling factor and construction cost are adopted to compare wind effects induced by the twenty-seven types of wind loads. The results show that there are three symmetrically distributed and three asymmetrically distributed wind loads, which can lead to more severe wind effects. The most adverse wind load pattern of all is the symmetrical distribution with the largest pressures around the stagnation point area, largest suctions in both sideward regions and lowest suctions in the leeward region.

1. Introduction

Natural draft cooling towers are hyperbolic reinforced concrete shell structures widely used in coal-fired and nuclear power plants as cooling devices. These structures are typically wind-sensitive due to the low and closely spaced frequencies. Along with increase of power demands and installed capacities of generator sets, current heights of cooling towers have been approaching 200 m [1]. More severe wind-resistant problems than before have been confronted by these large-scale towers in synoptic or non-synoptic boundary-layer-type strong winds [2–5]. Additionally, towers on the site of an actual power station are often in close proximity to each other or to other tall buildings, thus wind-induced pressures are significantly different from those on an isolated one. The variations of flows and flow-induced forces produced on each tower by other structures are commonly known as interference.

The initial attention to interference effects on cooling towers was paid by wind engineers and researchers due to the collapses of three cooling towers at Ferrybridge power station in 1965. The conclusions emerging from the subsequent inquiry into the failure showed that the complex groups of towers and buildings could give rise to significant loadings on downstream towers and to much more severe mean and fluctuating stresses in the tower shells than those in an isolated tower [6]. Since then, great effort has been made to study interference effects on wind loads and wind effects especially for large-scale cooling towers. Armit [7] quantitatively evaluated the variation of root-mean-square (RMS) stress with wind speed by the site model experiments of Ferrybrige power station in the wind tunnel. The results showed that RMS quasi-steady stresses vary as the square of wind speed and RMS resonant stresses have a 4th power variation when wind blows through a gap between upstream towers. Sun et al. [8] investigated mean and fluctuating pressure distributions on a group of two cooling towers by full-scale measurements. Cao et al. [9] studied the interference effects on wind pressures of eight large cooling towers arranged in parallelogram and rectangle shapes with the use of computational fluid

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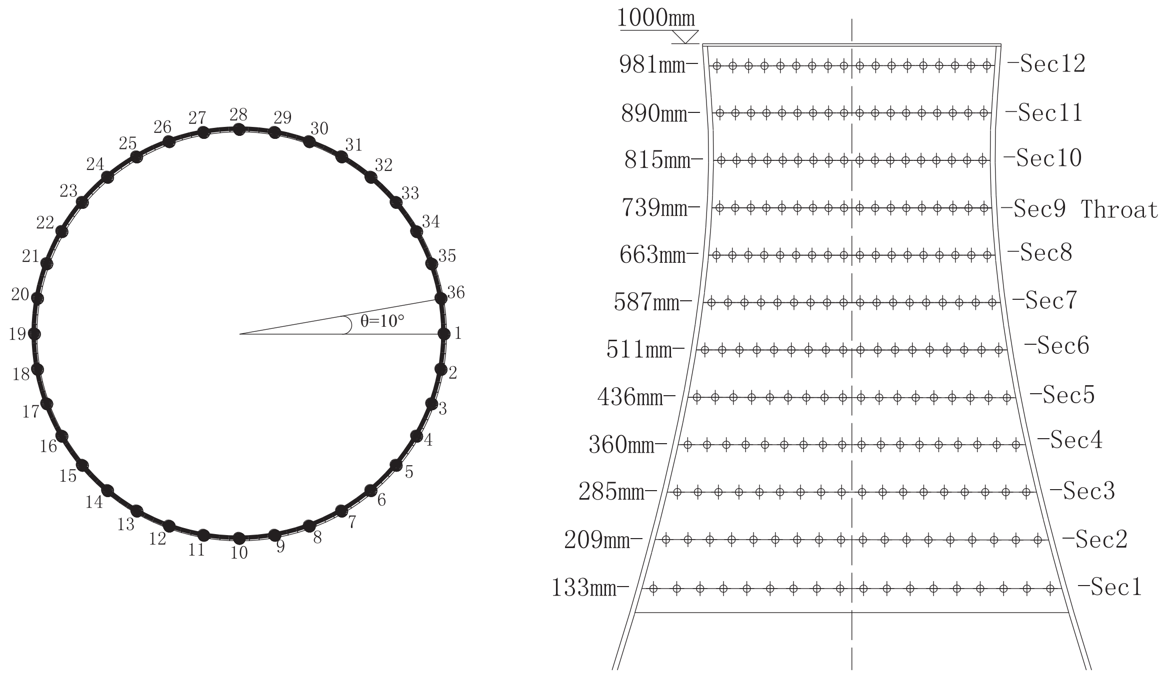

Fig. 1. Cooling tower model and layout of pressure taps on it.

dynamics, which has also been pervasively applied in the field of thermal engineering of cooling towers [10,11].

In order to quantify the loading or stress increases caused by group effects in the structural design of cooling towers, interference factors have been proposed and widely adopted by the available cooling tower codes [12–14], which is a global increase applied to the wind loads or wind-induced stresses of an isolated tower [15,16]. However, the method recommended by codes has two problems. One is the estimated loads are always conservative, despite the peak value can be covered [17]. Because strong effects are usually restricted to small ranges of the flow angle, the surrounding buildings provide a shelter effect for other wind directions. The other is the symmetrical loading distributions derived from the isolated tower cannot represent actual conditions as loads on disturbed cooling towers are asymmetrically distributed in most cases [18]. To the authors' knowledge, there has been no study on the effect of loading distributions on wind effects on cooling towers.

In the present study, a series of wind tunnel tests with two types of grouped arrangements for six towers were carried out, in which external surface pressures acting on towers were measured at several center-to-center distances and wind directions. The interfered wind loads were statistically analyzed and a number of typical patterns, which could represent actual wind loading distributions under interference were proposed. Subsequently, several adverse wind loading patterns were obtained by comparison of wind effects. Finally, the characteristic of the most adverse one was summarized.

2. Experimental procedure

2.1. The model

The six identical cooling towers investigated are of the form of a one-sheet hyperboloid. The main dimensions of the prototype structure are: total height of 200 m, throat height of 147.7 m, top diameter of 84 m, throat diameter of 80.33 m, shell base diameter of 137.48 m, throat thickness of 0.25 m. Each tower is supported by 96 V-shaped circular columns with the diameter of 1.3 m, which are placed around the lower shell edge at an angular distance of 7.5°.

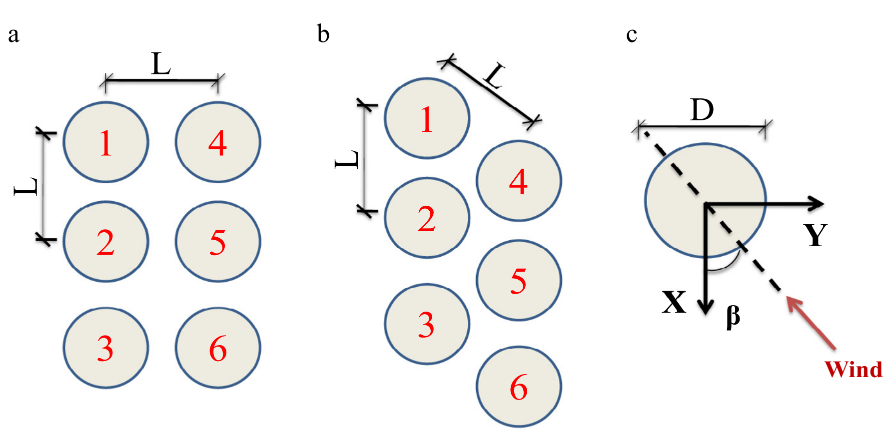

Fig. 2. Grouped arrangements for six towers, (a) rectangle configuration, (b) parallelogram configuration, (c) the definition of wind direction.